Diver Heating Using Hydrogen Catalytic Reactions
Concept Assessment

M. L. Nuckols
Ocean Engineering Program
U.S. Naval Academy
Annapolis, MD 21402
Phone: (410) 293-6429 Fax: (410) 293-2219 E-mail: Nuckols@nadn.navy.mil

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LONG-TERM GOAL

The long-term goal of this research is to develop a safe and efficient diver heater to minimize package size and power requirements and yet meet all the diver heating requirements for long duration Naval Special Warfare (NSW) missions.

OBJECTIVES

The technical objectives were to a) conduct a tradeoff analysis of different active heating methods for swimmer delivery vehicle (SDV) applications to quantify and compare the energy densities of each approach, b) construct a prototype heating circuit containing a heat exchanger incorporating a palladium on carbon catalyst bed, and c) conduct laboratory testing of prototype hydrogen catalytic heater and water heat exchanger to verify the energy density available from this heating method.

APPROACH

We first developed a conceptual hydrogen catalyst water heater design based on the results obtained previously from testing of an experimental breath heater (Nuckols *et al*, 1999). Theoretical hydrogen requirements and heat production capabilities that would satisfy the thermal protection requirements for Naval Special Warfare (NSW) missions were established. We then constructed an open circuit hydrogen catalyst water heater prototype to conduct laboratory testing to confirm these theoretical heating capabilities. A parametric analysis was performed to investigate the theoretical effects of circuit pressures, hydrogen injection rates, and circuit flow rates on heat production levels. FY01 efforts will be directed toward evaluating the performance of a semi-closed catalytic heating circuit for unmanned testing with closed-circuit hot water suits to (a) verify the feasibility of producing desired heating levels, (b) determine the most desirable hydrogen percentages and canister pressures to operate the catalytic heater, and (c) conduct laboratory testing of prototype hydrogen catalytic heater and water heat exchanger to verify the energy density available from this heating method. These energy densities will be compared with the size and weight characteristics of prototype SDV electrical resistive heaters.

WORK COMPLETED

Theoretical heat production rates have been established as described below. Preliminary testing results with an open circuit heater prototype have verified the feasibility of using hydrogen catalytic reactions as an efficient and easily controllable heat source for divers. Preliminary testing results with a semi-closed circuit system have shown good agreement with theoretical heat production rates.

RESULTS

The first prototype for the hydrogen catalytic combustion water heater consisted of a canister filled with a chemical catalyst surrounding a multiple tube heat exchanger, as shown in Figure 1.

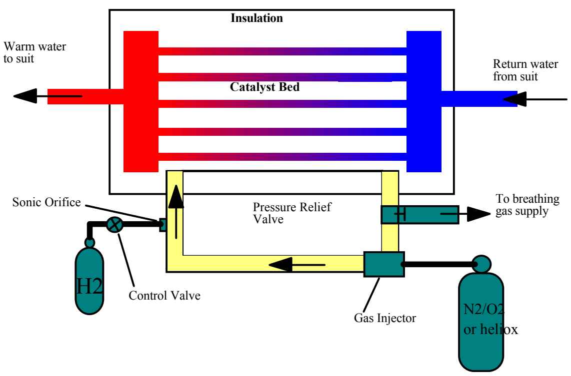

Figure 1: Sketch of hydrogen catalytic combustion heater concept.

Although it was anticipated that a small percentage of hydrogen could be injected into the gas mixture prior to it passing through the catalyst bed in a semi-closed circuit gas loop in a similar manner as the breath heater previously tested, initial testing used a steady, pre-mixed gas flow of air mixed with 1% hydrogen. As the gas mixture flowed through the canister the catalyst facilitated the reaction of hydrogen with a small amount of oxygen in the gas mixture to produce water vapor and heat. This heat was then transferred through a heat exchanger to a circulating water loop that would be used to carry this heat to the diver.

Figure 2 shows that simply varying the percentage of hydrogen present in the gas mixture can control the theoretical temperature rise across the catalyst bed. In addition, these theoretical temperature rises can be increased somewhat by using carrier gases other than air, as with the helium and oxygen mixture shown. These higher temperatures seen at the same volume fraction of hydrogen are a result of the lower mass of helium per mole of hydrogen when compared to air.

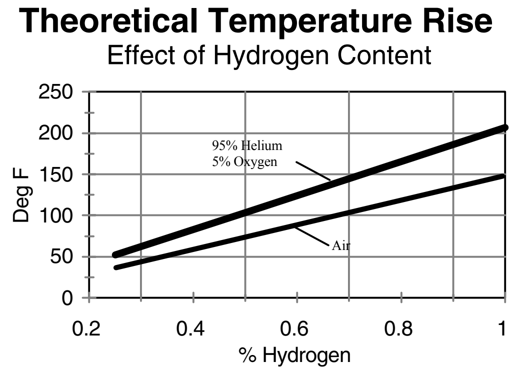

Figure 2: Effect of hydrogen percentage on gas temperature rise.

Actual temperature rises would be expected to be somewhat lower than these theoretical values since much of the heat generated in the catalyst bed will be transferred through the heat exchanger into the circulating water. Figure 3 shows the amount of heat that could theoretically be released by the combustion of 1% hydrogen in air at different air flow rates, and the amount of hydrogen combusted if the catalyst bed is at standard atmospheric pressure. Observe that at airflow rates of approximately 170 liter-min^{-1} (6 ft^3/min) the catalytic heater will consume 3.6 standard cubic feet (SCF) of hydrogen per hour and generate approximately 280 watts of heat.

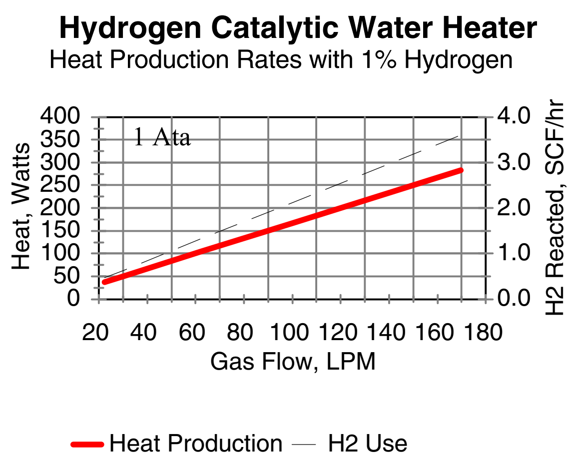

Figure 3: Heat production rates and hydrogen combustion rates with 1% hydrogen in air at surface pressure.

These heat production rates can be increased while using the same gas mixture by operating the catalyst heater at elevated pressures, as shown in Figure 4. Under these conditions at airflow rates of approximately 170 liter-min^{-1} (6 ft^3/min) the catalytic heater will consume approximately 24 standard cubic feet (SCF) of hydrogen per hour and will generate nearly 2 kilowatts of heat.

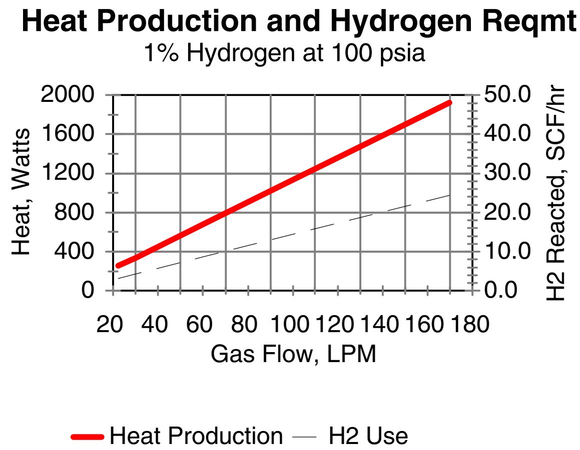

Figure 4: Heat production rates and hydrogen combustion rates with 1% hydrogen in air when operating the catalyst heater at 100 psi.

In April 2000, a laboratory test was conducted to confirm that theoretical heating levels could be obtained when using this hydrogen catalytic combustion heater as an active thermal protection system for divers. Approximately 0.5 kg of a catalyst consisting of 0.8% palladium deposited on extruded carbon pellets was added to the core of a tube and shell heat exchanger. The pellets were packed around stainless steel tubing running through the center core of the heat exchanger. During testing, water passed through this tubing, as well as through an annular space between the center core and a polyethylene outer jacket, at a rate of 0.2 gallons per minute. A steady flow of 1% hydrogen mixed in air at one atmosphere pressure passed through the catalyst-filled center core at a rate of 5.5 cubic feet per minute. Inlet and exit temperatures were monitored for the gas mixture and the water, as well as flow rates for each. Approximately 22% of the stored chemical energy from the hydrogen was transferred to the water stream during this steady flow testing. This relatively low conversion of the chemical energy in the hydrogen into useful thermal energy was not surprising. A large percentage of the available energy was lost to the environment by way of the hot air stream exhausted from the heater prototype. It was recognized that this wasted energy could be reduced considerably by using a more efficient heat exchanger and/or operating the gas stream in a closed, or semi-closed arrangement as shown in Figure 1, i.e., by recycling the hot gas stream back through the catalyst bed following the injection of a small percentage of make-up hydrogen back into the gas circuit. Preliminary testing results with a semi-closed circuit system have confirmed this expectation; see Figure 5.

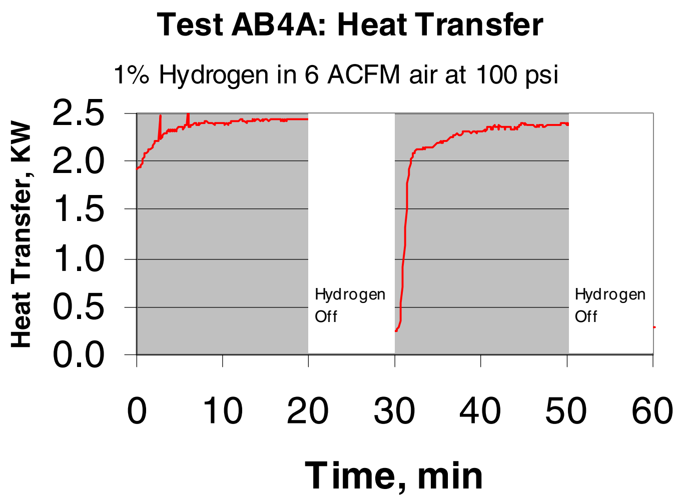

Figure 5: Heat production levels recorded during repeated supply and shutoff of hydrogen in laboratory prototype testing of the hydrogen catalytic heater concept.

IMPACT/APPLICATION

The hydrogen catalytic heater has already been shown to be an effective apparatus to warm and humidify diver's inspired gases in open-circuit, demand SCUBA systems with a small catalyst bed placed between the 1st and 2nd stage regulators, and in semi-closed circuit systems with the catalyst bed placed in the breathing circuit just upstream of a diver's mask or helmet. The hydrogen catalytic combustion water heater integrates this technology into a heater design for whole body thermal protection. This heating technique is expected to minimize the power and space requirements that must be dedicated to diver thermal protection within swimmer delivery vehicles, surface supported, or free-swimming missions.

TRANSITIONS

We are maintaining a close liaison with NEDU and the NSW community to ease the introduction of this type of diver heating system into service. During the past year we briefed this project with PMS 325 (contact: LT David Hoagland), NEDU (contact: CAPT Marie Knafelc), the VSW/SZ Diver Technology Workshop held in Panama City, FL during 11-13 July, the Fleet Diving Issues meeting in Panama City, FL during 9 August, UI 2000 conference in Houston, TX in during 24-26 January 2000, the PACON 2000 conference in Honolulu, HI on 8 June 2000, and Oceans 2000 conference during 10-14 September 2000. Upon satisfactory completion of this effort the results will be widely disseminated in an effort to gain commercial acceptance of this heating system for surface-supplied and free swimming applications.

RELATED PROJECTS

We are maintaining close liaison with Ken Fredrickson at CSS and LCDR Loring Crepeau, NEDU on a related diver heating effort for SDVs using electrical resistance heating elements.

REFERENCES

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